Claims

1. An ultrasonic transducer comprising:

a support element;

a first transducer array coupled to move with the support element and comprising a plurality of first transducer elements arranged along an azimuthal axis, said first transducer array comprising first and second ends spaced along the azimuthal axis and a first central image plane;

a second transducer array coupled to move with the support element and comprising a plurality of second transducer elements, said transducer array positioned near the first end of the first transducer array and comprising a second central image plane; and

a third transducer array coupled to move with the support element and comprising a plurality of third transducer elements, said third transducer array positioned near the second end of the first transducer array and comprising a third central image plane;

said first and second central image planes being non-parallel, and said first and third central image planes being non-parallel.

2. The invention of Claim 1 wherein the first and second central image planes are substantially orthogonal, and wherein the first and third central image planes are substantially orthogonal.

3. The invention of Claim 1 wherein the second and third transducer arrays are substantially shorter in length along the respective axes than is the first transducer array.

4. The invention of Claim 1 wherein the second and third transducer arrays each include substantially fewer of the respective transducer elements than does the first transducer array.

5. The invention of Claim 1 wherein the first, second and third transducer elements are each spaced with a respective pitch, and wherein

the pitch of the second transducer elements is a first integer multiple of the pitch of the first transducer elements.

6. The invention of Claim 5 wherein the pitch of the third transducer elements is a second integer multiple of the pitch of the first transducer elements.

7. The invention of Claim 6 wherein the first integer multiple is equal to the second integer multiple.

8. The invention of Claim 1 further comprising

a transmit beamformer and a receive beamformer coupled to the first, second and third transducer arrays.

9. The invention of Claim 8 wherein the transmit beamformer forms multiple simultaneous transmit beams.

10. The invention of Claim 8 wherein the receive beamformer forms multiple simultaneous receive beams.

11. The invention of Claim 8 wherein the transmit beamformer operates the first and second transducer arrays at different ultrasonic frequencies.

12. The invention of Claim 8 wherein the transmit beamformer operates the first, second, and third transducer arrays at a common ultrasonic frequency.

13. The invention of Claim 8 wherein the transmit beamformer operates the second and third transducer arrays with fewer scan lines than the first transducer array.

14. The invention of Claim 8 wherein the transmit and receive beamformers acquire concurrent images from the first, second and third transducer arrays for display.

15. The invention of Claim 8 wherein the transmit beamformer operates the second and third transducer arrays to acquire a plurality of frames from at least one of the second and third transducer arrays between adjacent frames from the first transducer array.

16. The invention of Claim 8 wherein the transmit beamformer operates the first transducer array to acquire a plurality of frames from the first transducer array between adjacent frames from the second transducer array.

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17. The invention of Claim 14 further comprising a display system coupled to the beamformers to display the concurrent images from the first, second and third transducer arrays.

18. The invention of Claim 1 further comprising an absolute sensor for at least one of displacement and orientation, said absolute sensor coupled to move with the support element.

19. The invention of Claim 18 wherein the absolute sensor comprises a magnetic sensor.

20. The invention of Claim 1 wherein at least a portion of the second transducer elements are connected in parallel with at least a portion of the first transducer elements, and wherein the portion of the second transducer elements are in a jumbled order with respect to the portion of the first transducer elements.

21. The invention of Claim 1 wherein at least two of the first, second and third transducer arrays form crossed arrays.

22. The invention of Claim 1 wherein the second and third transducer arrays are positioned alongside of and laterally spaced from the first transducer array.

23. The invention of Claim 1 further comprising third and fourth transducer arrays coupled to move with the support element and positioned near respective ends of the first transducer array, said third and fourth transducer arrays comprising respective fourth and fifth image planes oriented non-parallel to the first image plane.

24. A method for registering ultrasonic image information acquired from a target, said method comprising the following steps:

(a) acquiring a plurality of sets of image information with at least one ultrasonic transducer array, said at least one array moved between at least some of the sets of image information, said plurality of sets comprising a plurality of image data sets and a plurality of tracking sets;

(b) automatically determining a component of motion based on a comparison of at least a portion of the tracking sets acquired in step (a); and

(c) automatically using the component of motion determined in step (b) to register selected ones of the image data sets acquired in step (a).

25. The invention of Claim 24 wherein the at least one ultrasonic transducer array comprises an imaging array and at least one tracking array, wherein the imaging array defines an image plane, wherein the tracking array defines a tracking plane, and wherein the image plane is oriented at a non-zero angle with respect to the tracking plane.

26. The invention of Claim 24 wherein the sets of image information are oriented substantially parallel to one another, and wherein step (c) forms an extended field of view.

27. The invention of Claim 24 wherein at least some of the tracking sets do not intersect at least some of the image data sets.

28. The invention of Claim 24 wherein step (b) comprises the step of cross-correlating said at least a portion of the tracking sets.

29. The method of Claim 25 wherein the at least one tracking array comprises first and second tracking arrays, each positioned adjacent a respective end of the imaging array to acquire tracking sets in respective first and second tracking planes, and wherein step (b) determines the component of motion in both said first and second tracking planes.

30. The method of Claim 24 wherein the image data sets comprise information selected from the group consisting of B-mode information, color Doppler velocity information, color Doppler energy information, and combinations thereof.

31. The method of Claim ~~24~~ 1 comprising the further step of determining a second component of motion based on a comparison of at least some of the selected image data sets, and wherein step (c) comprises the step of using the second component of motion to register said image data sets.

32. The method of Claim 24 wherein the image data sets are acquired using a different frequency than that used in acquiring the tracking sets.

33. The method of Claim 24 wherein step (a) comprises the step of using dual beamformers to simultaneously acquire the image data sets and the tracking sets.

34. The method of Claim 33 wherein step (a) comprises the step of using respective bandpass filtering in association with the respective beamformers.

35. The method of Claim 24 wherein step (a) provides the tracking sets as scan-converted data.

36. The method of Claim 24 wherein step (a) provides the tracking sets as acoustic line data, prior to scan conversion.

37. The method of Claim 24 wherein step (b) performs the comparison using every Nth pixel of the tracking sets, where N is an integer greater than zero.

38. The method of Claim 24 wherein step (b) comprises the step of combining a plurality of measures of the component of motion.

39. The method of Claim 38 wherein the step of combining comprises the step of assigning weights to individual measures of the component of motion, each weight indicative of quality of the respective measure.

40. The method of Claim 39 wherein the step of assigning weights comprises the step of comparing spatially adjacent measures of the component of motion.

41. The method of Claim 39 wherein the step of assigning weights comprises the step of comparing successive measures of the component of motion.

42. The method of Claim 39 wherein the step of assigning weights uses fuzzy logic.

43. The method of Claim 38 wherein the combining step comprises the step of discarding low-quality measures of the component of motion.

44. The method of Claim 24 further comprising the step of:

(d) indicating to an operator when the component of motion determined in step (b) is outside a preferred range of values.

45. The method of Claim 24 further comprising the step of:

(d) alerting an operator when the determining step (b) is not operating effectively.

46. The method of Claim 25 wherein step (a) comprises the step of operating the imaging and tracking arrays in parallel.

47. The method of Claim 46 wherein step (a) comprises the step of operating the imaging and tracking arrays at differing voltage levels.

48. The method of Claim 24 further comprising the step of:

(d) interpolating between a plurality of measures of the component of motion determined in step (b).

49. The method of Claim 24 wherein the sets of image information are acquired in step (a) using a plurality of separate frequencies.

50. The method of Claim 24 wherein the sets of image information are acquired in step (a) using a plurality of different bandwidths.

51. The method of Claim 24 wherein the tracking sets comprise sets acquired using a plurality of different ultrasonic frequencies.

52. The method of Claim 24 wherein the tracking sets comprise sets acquired using a plurality of different ultrasonic bandwidths.

53. The method of Claim 24 wherein step (b) comprises the step of generating curve-fitted values derived from a plurality of measures of the component of motion.

54. The method of Claim 24 wherein step (b) comprises the step of adaptively varying a time interval between time of acquisition of the tracking sets used in determining the component of motion to cause the component of motion to approach a selected range.

55. The invention of Claim 24 wherein step (b) comprises the step of averaging a plurality of pixels of at least one of the tracking sets prior to determining the component of motion.

56. The method of Claim 24 further comprising the step of automatically varying intensity mapping of the tracking sets acquired in step (a) to enhance motion detection.

57. The invention of Claim 24 further comprising the step of:

(d) filtering at least said portion of the tracking sets of image information prior to the comparison of step (b).

58. The method of Claim 24 wherein step (b) comprises the step of repeatedly using a first one of the tracking sets of image information as a reference in a plurality of successive ones of the comparison of step (b) until the component of motion is determined with respect to said first tracking set of image information.

59. The method of Claim 24 wherein step (b) comprises the step of performing the comparison over a search region of the tracking sets of image information, wherein the search region is elongated in shape in a direction substantially aligned with the component of motion.

60. The method of Claim 24 wherein step (b) comprises the step of performing the comparison over a variable search region of the tracking set.

61. The method of Claim 60 wherein step (b) comprises the step of positioning the variable search region based on a previously-determined component of motion.

62. The method of Claim 60 wherein step (b) comprises the step of sizing the variable search region based on variability of a plurality of previously-determined components of motion.

63. The method of Claim 24 wherein step (b) comprises the step of performing a series of comparisons of the tracking sets, wherein the comparisons differ in resolution in at least one of spatial and signal level resolution.

64. The method of Claim 24 wherein step (b) comprises the step of correlating two non-parallel lines of image information included in two of the tracking sets of image information acquired in step (a) to determine vector components of the component of motion, said vector components aligned with said lines.

65. The method of Claim 24 further comprising the step of

(d) forming data-compressed versions of at least some of the image data sets and tracking sets acquired in step (a) prior to at least one of steps (b) and (c).

66. The method of Claim 65 further comprising the step of

(e) applying data decompression to the data-compressed versions of step (d) prior to at least one of steps (b) and (c).

67. The method of Claim 25 further comprising the step of (d) using the registered image data sets to form a 2D image in a plane obliquely oriented with respect to the image plane.

68. The method of Claim 24 wherein step (b) comprises the step of utilizing in the comparison only the tracking sets that correspond to selected portions of a cycle selected from the group consisting of an ECG cycle and a breathing cycle.

69. The method of Claim 24 wherein the information of the tracking sets used in the comparison of step (b) is selected from the group consisting of envelope-detected data prior to scan conversion, RF beamformer signals prior to envelope detection, and baseband beamformer signals prior to envelope detection.

70. The method of Claim 24 wherein the image data sets are acquired using a different frequency than that used in acquiring the tracking sets.

71. The method of Claim 24 wherein the image data sets are acquired using a different bandwidth than that used in acquiring the tracking sets.

72. The method of Claim 24 wherein the image data sets are acquired using a different azimuthal focus than that used in acquiring the tracking sets.

73. The method of Claim 24 wherein step (a) further comprises the step of using a different logarithmic compression of signal level for the image data sets than for the tracking sets.

74. The method of Claim 26 wherein the at least one transducer array comprises a first transducer array and at least one additional transducer array, wherein the image data sets are acquired using the first transducer array, and wherein the tracking sets are acquired using the at least one additional transducer array.

75. The method of Claim 74 wherein the first and at least one additional transducer arrays are co-linear and axially spaced from one another.

76. The method of Claim 74 wherein the first and at least one additional transducer arrays are positioned alongside of and laterally spaced from one another.

77. The method of Claim 24 wherein step (a) further comprises the step of automatically varying intensity mapping of the tracking sets to enhance motion detection.

78. The method of Claim 24 wherein the image data sets and the tracking sets are acquired using different transducer arrays.

79. The method of Claim 78 wherein the acquiring step comprises the step of multiplexing signals to the different transducer arrays via a common set of signal conductors.

80. The method of Claim 24 wherein the image data and tracking sets each comprise a plurality of scan lines, and wherein sets of one or more scan lines of the image data sets are interleaved in time with sets of one or more scan lines of the tracking sets.

81. The method of Claim 24 wherein step (a) comprises the step of forming multiple simultaneous transmit beams with the at least one transducer array.

82. The method of Claim 24 wherein step (a) comprises the step of forming multiple simultaneous receive beams with the at least one transducer array.

83. The method of Claim 24 wherein step (a) comprises the step of coherently forming at least the tracking sets.

84. The method of Claim 24 further comprising the step of (d) indicating to an operator when tissue contact is lost for a transducer array included in the at least one transducer array.

85. The method of Claim 24 wherein the selected ones of the image data sets comprise consecutively acquired image frames.

86. The method of Claim 24 wherein the selected ones of the image data sets comprise non-consecutively acquired image frames separated in time by at least one intervening image frame.

87. The method of Claim 24 wherein step (c) comprises the step of smoothly interpolating between the image data sets at a boundary between the selected image data sets.

88. A method for forming an extended field of view of a target, said method comprising the following steps:

(a) acquiring a plurality of sets of image information with an ultrasonic transducer array, said array moved substantially in an image plane between sets of image information;

(b) automatically determining rotational and translational components of motion in the image plane based on a plurality of comparisons of a single block of image information from a first one of said sets with a second one of said sets; and

(c) automatically using the components of motion determined in step (b) to register said first and second sets to form an extended field of view.

89. An ultrasonic transducer comprising:

a support element;

a first transducer array coupled to move with the support element and comprising a plurality of first transducer elements arranged along an azimuthal axis, said first transducer array comprising first and second ends spaced along the azimuthal axis and a first central image plane;

a pair of second single-element transducer elements positioned on respective sides near the first end of the first transducer array;

a pair of third single-element transducer elements positioned on respective sides near the second end of the first transducer array.

90. The invention of Claim 89 wherein at least some of the second and third single-element transducer elements comprise respective elongated elements oriented to extend substantially parallel to the azimuthal axis.

91. The invention of Claim 89 wherein at least some of the second and third single-element transducer elements comprise respective circular elements.

92. The invention of Claim 91 wherein at least some of the second and third single-element transducer elements are pointed in separate directions.

93. The invention of Claim 89 wherein at least some of the second and third single-element transducer elements are focused at a selected range.

94. The invention of Claim 89 wherein at least one of the second and third single-element transducer elements is superimposed on the first transducer array.

95. An ultrasonic transducer comprising:

a support element;

a first transducer array coupled to move with the support element and comprising a plurality of first transducer elements arranged along an azimuthal axis, said first transducer array comprising first and second ends spaced along the azimuthal axis and a first central image plane;

a second transducer array coupled to move with the support element and comprising a plurality of second, annular transducer elements positioned near the first end of the first transducer array;

a third transducer array coupled to move with the support element and comprising a plurality of third, annular transducer elements positioned near the second end of the first transducer array.

96. The invention of Claim 95 further comprising:

a fourth transducer array coupled to move with the support element and comprising a plurality of fourth, annular transducer elements positioned near the first end of the first transducer array; and

a fifth transducer array coupled to move with the support element and comprising a plurality of fifth, annular transducer elements positioned near the second end of the second transducer array.

97. The invention of Claim 95 wherein at least one of the second and third transducer arrays is superimposed on the first transducer array.

98. The invention of Claim 96 wherein the second and fourth transducer arrays are pointed in separate directions and wherein the third and fifth transducer arrays are pointed in separate directions.

99. A method for creating an ultrasonic scan comprising the following steps:

(a) providing an ultrasonic transducer comprising an imaging transducer array and a tracking transducer array, said tracking transducer array comprising a plurality of transducer elements;

(b) applying a respective transmit signal to each of the transducer elements, each transmit signal comprising a plurality of cycles characterized by a frequency; and

(c) varying the frequency to selectively control an associated ultrasonic scan direction.

100. The method of Claim 99 further comprising the step of (d) using tracking data from the tracking transducer array to align image data from the imaging transducer array in three dimensions.

101. The invention of Claim 99 wherein step (b) comprises the step of generating the transmit signals by progressively delaying an input signal such that each of the transmit signals is delayed by a time period equal to $\Delta T \bullet n$ with respect to the input signal, where n is a non-negative integer.

102. The invention of Claim 99 wherein step (b) comprises the step of directly generating the transmit signals.

103. The invention of Claim 99 wherein each transmit signal comprises a respective tone burst.

104. The invention of Claim 102 wherein each tone burst is 5 to 10 cycles in length.

105. A method for detecting an erroneous motion estimate comprising the following steps:

(a) providing an ultrasonic transducer comprising an imaging transducer array and at least three tracking transducer arrays, each tracking transducer array comprising at least one transducer element;

(b) collecting tracking data from each of the tracking transducer arrays;

(c) developing at least three motion estimates from the tracking data, each motion estimate associated with a respective tracking transducer array; and

(d) detecting an unreliable one of the motion estimates based on a comparison of the motion estimates.

106. A method for registering ultrasonic image information acquired from a target, said method comprising the following steps:

(a) acquiring a plurality of sets of image information with at least one ultrasonic transducer array, said at least one array moved between at least some of the sets of image information, said plurality of sets comprising a plurality of image data sets and a plurality of tracking sets;

(b) automatically determining a component of motion based on a comparison of at least a portion of the tracking sets acquired in step (a); and

(c) automatically using the component of motion

determined in step (b) to register selected ones of the image data sets acquired in step (a);

wherein step (a) comprises the step of transmitting ultrasonic energy concentrated near a fundamental frequency into a target; and

wherein at least one of the image data sets and the tracking data sets comprises a selectively received harmonic component of received ultrasonic echo information, said harmonic component concentrated near a harmonic of the fundamental frequency.

107. The method of Claim 106 wherein the image data sets comprise the selectively received harmonic component.

108. The method of claim 106 wherein the tracking data sets comprise the selectively received harmonic component.

109. The method of Claim 106 wherein the image data sets and the tracking data sets both comprise ~~the~~ selectively received harmonic component.

110. The method of Claim 107 wherein the tracking data sets comprise a second selectively received harmonic component of received ultrasonic echo information.

111. The method of Claim 110 wherein the first-mentioned and second selectively received harmonic components differ in bandwidth.

112. The method of Claim 106 wherein steps (a)-(c) are performed during a medical ultrasound examination session, and wherein the method comprises the further step of (d) maintaining the target free of additional non-linear contrast agent throughout the entire medical ultrasound examination session.

113. A method for forming an extended field of view of a target, said method comprising the following steps:

(a) acquiring a plurality of sets of image information with an ultrasonic transducer array, said array moved substantially in an image plane between sets of image information;

(b) automatically determining components of motion in the image plane based on a plurality of comparisons of a single block of image information from a first one of said sets with a second one of said sets; and

(c) automatically using the components of motion determined in step (b) to register said first and second sets to form an extended field of view;

wherein step (a) comprises the step of transmitting ultrasonic energy concentrated near a fundamental frequency into a target;

wherein at least some of the sets of image information comprise a selectively received harmonic component of received ultrasonic echo information, said harmonic component concentrated near a harmonic of the fundamental frequency.

114. The method of Claim 113 wherein steps (a)-(c) are performed during a medical ultrasound examination session, and wherein the method comprises the further step of (d) maintaining the target free of additional non-linear contrast agent throughout the entire medical ultrasound examination session.

115. The method of Claim 113 wherein the components of motion comprise rotational and translational components of motions.

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